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ABSTRACT

It was reasoned that if the right ear/left brain hemisphere is more efficient than the left ear/right hemisphere at extracting the meaning of a sentence, then verbatim information presented to the right ear may be more difficult to retrieve than verbatim information presented to the left ear immediately after the sentence is heard. This idea was tested on 64 college students with normal hearing, using a Sternberg item-recognition task. Results indicated that sentences presented to the right ear did produce a longer recognition latency than sentences presented to the left ear. The faster left ear response occurred with both a manual and a spoken response. These results were interpreted as support for greater "depth of processing" by the right ear/dominant hemisphere than the left ear/minor hemisphere. (Author/RL)

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# CEREBRAL ASYMMETRY, SENTENCE STRUCTURE, MODE OF RESPONSE, AND RECOGNITION LATENCY[1]

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Clinical and experimental evidence suggests that the human brain is functionally asymmetrical.[2] It appears that the left or dominant hemisphere is particularly involved in speech and language and the right or nondominant hemisphere in nonlinguistic functions.[3] This does not mean, however, that communication behavior is neatly divided up between the two hemispheres of the brain, with verbal behavior controlled exclusively by the left hemisphere and nonverbal behavior by the right hemisphere. For example, the dominant hemisphere is involved in vision and motor skills; and it is not at all clear how much language processing can occur in the minor hemisphere. For instance, tests of people with a split brain (i.e., the corpus collasum, which connects the brain's left and right hemispheres, has been severed or is not intact) show a certain amount of language comprehension in the hemisphere, ranging f: .n comprehension of single words to sentences (see Gazzaniga, 1967; Gazzaniga and Sperry, 1967). Recently, researchers have compared normal males and females on tasks related to hemisphere specialization. In a review of this work, Goleman (1978) pointed out that adult females, more than males, appear to duplicate verbal and spatial abilities on both sides of the brain. It is also well known that prior to puberty, damage to the dominant hemisphere results in less severe disruption of language behavior than after puberty (Lenneberg, 1967; Kinsbourne, 1975). In direct contrast to a verbal-nonverbal division of labor between the hemispheres, Bever (1975) has presented evidence to argue for the position that "...it is the kind of processing that determines behavioral asymmetry, not the modality in which the

processing is categorized (e.g., language, music, vision, etc.)" (p. 254). Taken together, these findings would caution us against any simple, dichotomous view of brain organization of verbal and nonverbal abilities. The purpose of this study is to learn more about how the two sides of the intact, adult brain differ in initial sentence processing, i.e., processing that goes on during and immediately after a sentence is heard. It is assumed in the research presented here that the better we understand the organization of behavior, the better we will understand the process of communication.

There is reason to believe that a sentence presented to the right ear/left hemisphere is more fully processed than a sentence presented to the left ear/right hemisphere right after the sentence ends. Many studies have shown that subjects are better at recognizing and recalling speech presented to the right ear compared to speech presented to the left ear (Bever, 1970; Bryden, 1965; Kimura, 1967; Milner, 1962; Shankweiler and Studdert-Kennedy, 1967). Moreover, some evidence suggests that the dominant ear/hemisphere is particularly sensitive to sentence structure. For instance, Bever (1970) reported an asymmetry of the ears for the immediate processing of sentences but not lists of words. Subjects successfully recalled more sentences heard in the right ear than the left ear. In addition, he found that when subjects hear various sentence forms (e.g., active, passive, negative, question, negative passive, passive question, negative passive question) in the right ear, they show fewer meaning changing syntactic errors than for sentences presented to the left ear. Bever concluded that "...

the dominant ear is more directly involved in the processing of the syntactic and semantic aspects of speech and that its involvement qualitatively affects perceptual judgments and immediate recall" p. 14). In the present study, it was reasoned that--right after a sentence is heard--a sentence presented to the right ear is more fully processed than a sentence presented to the left ear. Craik and Lockhart (1972) suggest that a more fully or deeply processed sentence implies a greater degree of semantic analysis. They add that, "since the organism is normally concerned only with the extraction of meaning from the stimuli, it is advantageous to store the products of such deep analysis, but there is usually no need to store the products of preliminary analyses" (p. 675). Hence, information concerning the exact words of the just-heard sentence ought to be less accessible in the dominant hemisphere than the minor hemisphere. That is, if the subject is required to retrieve information about the surface structure of a sentence right after the sentence ends, e.g., whether or not a particular word occurred in the sentence, then the subject should have more trouble with right ear than left ear presentations.

Another factor which affects the accessibility of a word in a sentence just heard is its location in the sentence. Some studies of sentence processing have been interpreted to show that sentences are processed clause-by-clause (Abrams, 1973; Bever, Garrett, and Hurtig, 1973; Bever, Lackner, and Stolz, 1969; Bever, Kirk, and Lackner, 1969; Caplan, 1971, 1972; Fodor and Bever, 1965; Garrett, Bever, and Fodor, 1966; Holmes and Forster, 1972;

Jarvella, 1970; Jarvella and Herman, 1972; Wingfield and Klein, 1970). In addition, it has been found that for a two-clause sentence, initial clause words are less accessible than final clause words, independent of serial position within the sentence (Jarvella, 1970; Jarvella and Herman, 1972, Caplan, 1971, 1972). This finding supports the idea that initial clauses are assigned meaning before final clauses are assigned meaning. We may expect, then, that initial clause words presented to the right ear will cause greater difficulty in a word recognition task than any other clause position-ear combination. Finally, since this difficulty in word recognition is thought to occur at the memory search-match stages in the recognition process, no matter how the subject signals his/her response, the response ought to show the added processing time. To test this idea, a manual and a spoken response were employed.

To sum up, it has been proposed that the right ear will differ from the left ear in the depth of initial sentence processing. As a result, the exact words in right ear sentences will be less accessible than final clause words. The added time it takes the subject to retrieve right ear and/or initial clause information should show up in a manual response as well as a spoken response.

This study tests the following three hypotheses: (1) when subjects hear a sentence in the right ear followed by a probe word, they take longer to indicate that the probe was a word that occurred in the sentence than when the sentence is heard in the left ear; (2) the words in the initial clause of a two-clause sentence presented to the right ear take longer to recognize than for any

other ear-clause-position combination; (3) a manual and a spoken response both show longer recognition latency for right ear than for left ear presentations.

## Method

### Subjects

The subjects were sixty-four volunteers at the Stamford Campus of The University of Connecticut. Subjects were right handed and native speakers of English with normal hearing.

### Materials

Sixty-four two-clause test sentences were constructed. In each sentence, one clause met the following conditions: (a) it consisted of between nine and eleven monosyllabic words (with the exception of two disyllabic target words); (b) it contained a target word which could function in two positions without altering the meaning of the sentence; (c) it could function either as a main or subordinate clause in either initial or final position. The sole restriction for the other clause was that it satisfy condition (c). Thus, a test sentence exhibited eight alternative forms, which will be referred to as a set. The following exemplar illustrates the permutations by serial position of the target word within the clause, clause type, and clause position.

Set I

1. Though the clowns and the trained bear were fun to watch, the man on the flying trapeze was the most breath-taking act of all.

2. Though the trained bear and the clowns were fun to watch, the man on the flying trapeze was the most breath-taking act of all.



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3. The clowns and the trained bear were fun to watch, though the man on the flying trapeze was the most breath-taking act of all.

4. The trained bear and the clowns were fun to watch, though the man on the flying trapeze was the most breath-t[illegible] act of all.

5. Though the man on the flying trapeze was [illegible] most breath-taking act of all, the clowns and the trained bear were fun to watch.

6. Though the man on the flying trapeze was the most breath-taking act of all, the trained bear and the clowns were fun to watch.

7. The man on the flying trapeze was the most breath-taking act of all, though the clowns and the trained bear were fun to watch.

8. The man on the flying trapeze was the most breath-taking act of all, though the trained bear and the clowns were fun to watch.

Seven other sets of test sentences, differing in semantic content, were constructed. Across sets, target words were distributed in various serial positions, ranging from one to eight syllables from the beginning of the clause.

Thirty additional sentences were constructed. Six served as practice sentences, three subordinate-main and three main-subordinate sentences. For each clause order (subordinate-main and main-subordinate), one probe was from the beginning of the sentence, one was from the end of the sentence, and one was not present in the sentence. The remaining 24 sentences served as filler sentences to vary the serial position of the target word. The filler sentences consisted of 12 subordinate-main and 12 main-subordinate sentences. For each clause order, four probes were from an extremely early position in the sentence, four were from an extremely late position, and four were not present in the sentence.

Design

The design is a 2X2X2X2X2X2 analysis of variance having 3 between-subject and three within-subject variables. Between-subject variables were Ear (sentences presented to the right ear or the left ear), Mode of Response (manual vs. oral), and Sentence-Probe Orientation (the sentence in one ear and the probe in the other vs. sentence and probe in the same ear). Within-subject variables were Clause Type (main vs. subordinate), Clause Position (initial vs. final), and Location of the Target Word Within the Clause (early vs. late).

The eight presentation lists were constructed in the following way. Each list (tape) consisted of only one sentence from each set. Within each half of a tape there was an equal number of subordinate-main and main-subordinate test sentences and an equal number of occurrences of a target word in subordinate and main clauses for each clause order. In short, each half of each tape contained an equal number of subordinate and main clauses in initial and final position. Hence, each half of each tape had one target word from an initial subordinate clause, one from an initial main clause, one from a final subordinate clause, and one from a final main clause. Within these limits, test sentences were randomly ordered. An equal number of subordinate-main and main-subordinate filler sentences occurred in each half of the list, with an equal number of early, late, and not present target words. The order of test sentences and fillers was constant across the tapes.



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## Apparatus

The eight presentation lists were tape recorded by a male Standard American speaker. Filler and test sentences were recorded on one channel in a monotone (an oscillator aided in keeping pitch constant) with an attempt to reduce clause boundary juncture. Sentences were recorded in this way to insure that subjects segmented the sentences according to syntactic knowledge rather than intonational cues. Probes were recorded on a second channel. The mean interval between the end of the last word of the test sentence and onset of the probe was 327 milliseconds with a standard deviation of 100 milliseconds.

Sentences and probes were presented auditorially to subjects with a tape recorder and stereophonic headphones. Onset of the probe activated a voice operated relay which started a millisecond timer. In the case of an oral response, the subject's spoken response stopped the timer via a microphone and a second voice operated relay. In the case of a manual response, the subject stopped the timer by moving a switch with his/her right hand.

## Procedure

Subjects were tested individually. The subject heard a sentence immediately followed by a probe word. Either sentences were heard in the left ear/probes in the right or sentences were heard in the right ear/probes in the left or both sentences and probes were heard in the same ear. The subject was instructed to say "In" if the probe was present in the sentence and "Out" if it was not, in the oral condition. In the manual condition, the subject was instructed to throw a switch marked "In" or another marked "Out." The subject

was instructed to respond as rapidly and as accurately as possible. Reaction time was measured from the onset of the probe to the subject's response.

## Results

Each subject contributed a maximum of 8 data points. Of the overall maximum of 512 data points, some were missing due to equipment failure (under 1%), responses 2 or more standard deviations from a subject's mean recognition latency for test sentences (1.8%), and/or errors. If 3 or more of a subject's 8 data points were missing, that subject was replaced. Overall, 15% of the subjects were replaced and their data excluded from further analysis. The overall error rate for the remaining subjects was 8% (42 errors). Recognition latency data for error trials was not included in the subsequent analyses. The percentage of incorrect responses (based on a total of 42 errors) varied with type of response (manual = 38%; oral = 62%) and with clause position of the target word (initial clause = 93%; final clause = 7%). The right ear accounted for 55% of the errors and the left ear, 45%.

A mean reaction time was computed for each subject for each combination (2 instances) of target presentation condition, i.e., clause position (initial vs. final), location of the target word within the clause (early vs. late), and type of clause (main vs. subordinate). A grand mean for each condition was obtained across the thirty-two super subjects.[4] Table 1 shows the means for initial and final clauses heard in the right and left ears and responded to manually or orally. The analysis of variance reported here used

subject means (2 sentences for a given target presentation condition) as single scores.

Insert Table 1 about here

Presentation of the sentence to the left or the right ear, mode of response (manual vs. oral), and location of the target word in the sentence (initial clause vs. final clause) all had an effect on reaction time. On the average, subjects took about 100 milliseconds longer to respond to a sentence heard in the right ear/left hemisphere than to a sentence heard in the left ear/right hemisphere. Subjects took about 137 milliseconds longer to respond to initial clause targets than final clause targets. And, subjects took about 113 milliseconds longer to respond orally than manually.

An analysis of variance was performed to assess the significance of these observations and to test for interactions between sentence ear (right vs. left), mode of response (manual vs. oral), sentence-probe ear orientation (same vs. mixed), clause type (main vs. subordinate), clause position (initial vs. final), and target position within the clause (early vs. late). Three main effects were found. First, reaction time for sentences heard in the left ear/minor hemisphere was significantly faster than reaction time for sentences heard in the right ear/dominant hemisphere [$F(1,24)=7.902$, $p<.01$]. Second, the effect of mode of response was significant [$F(1,24)=10.372$, $p<.01$]. Third, subjects took significantly longer to recognize initial clause words than final clause words [$F(1,24=53.111$, $p<.01$].

A significant interaction ($p<.05$) was found for clause position (initial vs. final) and the ear hearing the sentence (left vs. right). The location of a target word in the initial clause of a

sentence resulted in a greater increase in reaction time for sentences presented to the right ear than for sentences presented to the left ear, as shown in Fig. 1.

Insert Fig. 1 about here

Four higher order interactions significantly affected reaction time, ($p < .05$): (1) clause type (main vs. subordinate) X position of the target word within the clause (early vs. late) X sentence-probe ear orientation (same vs. mixed); (2) clause position (initial vs. final X early/late X ear (right vs. left); (3) main/subordinate X initial/final X early/late X mode of response (manual vs. oral); (4) main/subordinate X initial/final X early/late X ear X mixed/same. No attempt was made to interpret these higher order interactions.

Finally, two points are worth noting. The first concerns the effect of ear orientation, i.e., the ear hearing the sentence and the ear hearing the probe. Mean reaction time scores were computed for sentence-probe ear orientation (see Table 2). Collapsing data across the sentence ear, probe ear did not have a significant

Insert Table 2 about here

effect upon recognition latency ($T=48$, $p > .05$), Wilcoxom Matched-Pairs Signed-Ranks Test, two-tailed. But the effect of the location of the sentence in the left or right ear does not appear to be independent of the location of the probe word, $p(x_1^2 \geq 27.71) = .01$, by Chi-Square Test of Association. It appears that subjects are fastest when sentences are heard in the left ear and probes in the right.

The last point concerns the speed of memory search, approximated from the mean difference in syllables between early and late target words within the clause and the mean difference in reaction time between these serial positions. Scanning was performed at the rate of 31 milliseconds/syllable. This rate is remarkably similar to scanning rates reported by Sternberg (1969) in a series of studies on memory search of lists of items.

## Discussion

Ordinarily, the right ear/left hemisphere is said to show an advantage in speech and language tasks. Under experimental conditions, speech presented to the right ear is usually reported faster and with greater accuracy than speech presented to the left ear. Clinical evidence also demonstrates that the right ear is more strongly connected to the left or dominant hemisphere than is the left ear, and that the right ear/left hemisphere is especially involved in speech representation. In this study, however, a recognition task using sentences and probe words was employed which, it was hypothesized, would produce longer recognition latency for the right ear/left hemisphere than for the left ear/right hemisphere. This hypothesis received support. When subjects heard a sentence in the right ear, immediately followed by a probe word, they took significantly longer to indicate that the probe word was a word in the sentence than when the sentence was heard in the left or nondominant ear.

The findings in this experiment are consistent with the idea that sentences are processed over time with some parts of the sentences more fully processed than other parts right after the sentence ends. For instance, in keeping with the clause-by-clause



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principle, we may assume that, right after the sentence ends, the initial clause is more fully processed than the final clause (Jarvella, 1970; Jarvella and Herman, 1972). That is to say, following Craik and Lockhart's (1972) conception of "depth of analysis," the memory trace for the initial clause is more likely to be stored in a semantic code than the memory trace for the final clause. The final clause is more likely to be at some intermediary level of processing, between pattern recognition and extraction of meaning. Once the meaning of a segment has been assigned, preliminary analyses are lost. Hence, it becomes more difficult to recognize the exact words in a sentence after those words have been fully processed. This would help to explain why the right ear produced longer recognition latency than the left ear. Right ear sentences were more deeply processed by the time the subject heard the probe word than the left ear sentences, and, therefore, it was harder to retrieve information from right ear sentences than left. The initial clause heard in the right ear caused the greatest difficulty (Hypothesis 2) since, right after the sentence ends, initial clauses are more deeply processed than final clauses and the right ear/left hemisphere is specialized for extracting the semantic reading from a linguistic expression. Evidence from this study did support this idea. Also, some findings by Green (1975) lend support to the idea that different levels of representation influence recognition latency. Green found that when subjects listen to a sentence for comprehension (to produce a sentence semantically related to the presented one), they take longer to recognize a phrase-related (i.e., semantically related) probe than a rhyming probe. But when the subjects listen for

memorization (to recall the presented sentence), they take longer to recognize a rhyming probe than a phrase-related probe. As part of the same study, it was also found that subjects recognize identical probes (i.e., the probe matches a word in the sentence) about 100 milliseconds faster in the memorization condition than in the comprehension condition.

In the present study, we must consider the possibility that the right ear showed increased recognition latency over the left ear due to interference between stimulus presentation and response, i.e., speech input and either a spoken response or a right hand, manual response (see Brooks, 1968; Kinsbourne and Cook, 1971). But interference does not go very far towards explaining these data. For instance, we might expect to find more interference between speech presented to the right ear and a spoken response than speech presented to the left ear and a spoken response, while a manual response is unaffected--i.e., an interaction for ear by mode. But this interaction is not significant. Both the spoken and the manual response show a longer recognition latency for right ear sentences than for left (Hypothesis 3). In addition, it follows from an interference explanation that subjects would have special difficulty with final clauses heard in the right ear and responded to orally, i.e., an interaction for clause position by ear by mode. But this interaction is not found. Final clauses heard in the right ear do not produce longer reaction times than for initial clauses with either mode of response.

Finally, the results of this study imply that the minor hemisphere is capable of carrying out preliminary analyses involved in sentence

perception. We cannot tell from this study whether or not information must be transferred across the corpus collasum (see Bever, 1975). We do know that subjects make far more errors with initial clause target words than final clause target words heard in both ears, and initial clause target words produced significantly longer recognition latency for both ears. Taken together, the results of this study are interpreted as support for the idea that the minor hemisphere differs from the dominant hemisphere in the depth of processing that is carried out during and immediately after the sentence is heard. We may speculate that the minor hemisphere's inferior ability at sentence comprehension is a function of its (shallow) depth of processing coupled with a limited capacity perceptual/memory system. One may imagine that the right hemisphere suffers from a linguistic traffic jam, while the left hemisphere is able to rapidly transform verbal input to a semantic code and thereby clear the central mechanisms needed for preliminary analysis. We need more evidence to test this idea that right after sentences are presented to the right ear/left hemisphere, they are represented semantically to a greater extent than sentences presented to the left ear/right hemisphere.

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[2]Normally, one hemisphere in the adult brain is dominant in the processing of speech stimuli (Bever, 1970; Geschwind, 1965; Hecaen and Ajuriaguerra, 1964; Kimura, 1967; Milner, 1962; Mountcastle, 1962; Teuber, Battersby, and Bender, 1960; Zangwill, 1960).

[3]It has been estimated that the left hemisphere is dominant for speech in approximately ninety percent of right handed adults and sixty percent of left handed adults (Branch, Milner, and Rasmussen, 1964; Bryden, 1965; Kimura, 1967; Satz, Achenbach, Pattishall, and Fennell, 1965). All the studies discussed in this paper used right handed adults; therefore, to simplify matters, we will speak as if the left hemisphere is dominant for speech. Since each hemisphere has a functionally primary neurological connection with the contralateral ear (right ear-to-left hemisphere, left ear-to-right hemisphere; see Kimura, 1967), the right ear will be referred to as dominant and the left ear as non-dominant

[4]Since the tapes were not fully balanced for location of the target word within the clause (i.e., early vs. late), subjects were paired, such that a subject who heard a test sentence with, say, a subordinate, initial clause, early target word was randomly paired with a subject who heard the same sentence with a subordinate,

initial, late target word. In this way super subjects were constructed so that interferences could be made about search within the clause structure. This allowed for comparison with earlier results (Shedletsky, 1975) which showed that subjects take longer to recognize a word located late in a subordinate clause than early and the reverse for main clauses. While the results of this study show a tendency for this interaction between type of clause and serial position of the target word within the clause [$F(1,24) = 3.712$, $p > .05$]. It does not approach significance, and this issue is not discussed further in this paper.

Table 1

Mean Reaction Time (in Milliseconds)

| | Ear Hearing the Sentence | | | | |
|---|---|---|---|---|---|
| | Left | | Right | | |
| | Response Type | | Response Type | | |
| Clause-Location in the Sentence | Manual | Oral | Manual | Oral | Overall Location Mean |
| Initial | 464 | 629 | 662 | 713 | 617 |
| Final | 394 | 509 | 447 | 569 | 480 |
| Overall Ear Mean | 499 | | 598 | | |



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Table 2

Mean Recognition Latency (in Milliseconds) as a Function of the Ear Hearing the Sentence and the Ear Hearing the Probe Word

| | Sentence Ear | | |
|---|---|---|---|
| Probe Ear | Left | Right | Overall |
| Left | 528 | 596 | 562 |
| Right | 446 | 608 | 527 |
| Overall | 487 | 602 | |



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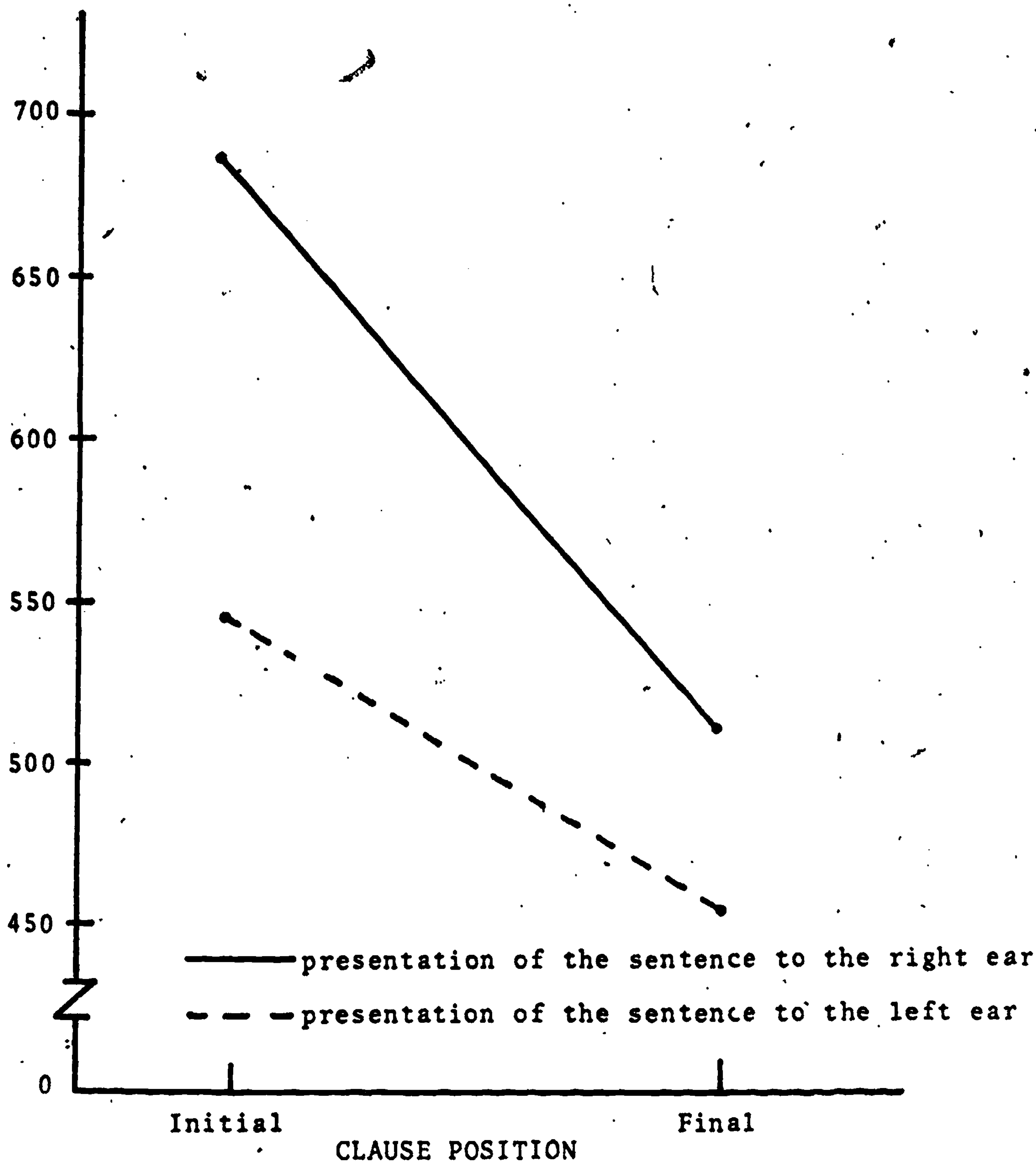


Fig. 1. The effects of clause position of the target word (initial vs. final clause) on the relationship between reaction time and the ear hearing the sentence (left vs. right).